

Assessment of Thermal Performance of Green Building Materials Produced with Plant Oils

Figen Balo¹, H. Lütü Yucel²

¹Department of Industrial Engineering, Firat University, 23279 Elazığ, Turkey

²Department of Mechanical Engineering, Firat University, 23279 Elazığ, Turkey

¹figenbalo@gmail.com, ²hlyucel@gmail.com

Abstract

The purpose of this study was to investigate the potential utilisation of vegetable oils in fly ash and clay, as binding, to develop construction materials that could be used for walls.

In present work, fly ash, natural clay and four different kinds of epoxidized vegetable oils (epoxidized soybean oil, epoxidized sunflower oil, epoxidized olive oil and epoxidized palm oil) were used to produce 180 kinds of composite materials and by analyzing the thermal conductivity coefficients of these novel materials, their use as a construction material was investigated.

The lowest value of thermal conductivity, 0.25 W/mK, was measured for the sample with a 70% fly ash /30% clay ratio and 50% epoxidized sunflower oil processed at 200°C; while the highest value of thermal conductivity, 0.496 W/mK, was measured for the sample with a 30% fly ash /70% clay ratio and 40% epoxidized soybean oil processed at 160°C. The lowest values of thermal conductivity for the samples with epoxidized olive oil and epoxidized palm oil processed at 200°C were obtained 0.255 and 0.258 W/mK, respectively. The lowest value of thermal conductivity was obtained from the highest process temperature at use of the epoxidized vegetable oils. Density and thermal conductivity decreased with the increase of epoxidized vegetable oils and FA at all levels of replacements. Moreover, with increasing of process, temperatures decreased density and thermal conductivity. The results showed that thermal conductivity of the building material increased when the high clay ratio was used in the preparation of the material composition. Results have also indicated an interesting potential for the fly ash recycling and epoxidized vegetable oils renewable to produce useful materials.

Keywords

Construction Material; Epoxidized Vegetable Oils; Mechanical Properties; Fly Ash; Thermal Conductivity

Introduction

Recently, the use of renewable sources in the preparation of various industrial materials has been revitalized because of the environmental concerns. Many researchers have invested the modification of

traditional materials to make them more user-friendly, and into designing novel biocomposites out of naturally occurring materials. The belief is that biocomposite materials will reduce the need for petrol-based production (thus reducing pollution) at a low cost, thereby producing a positive effect both environmentally and economically. Natural oils are considered to be the most important class of renewable sources. They can be obtained from naturally occurring plants, such as sunflower, cotton, linseed (Güner et al.). Natural oils are tri-glyceride esters of fatty acids, the general structure of which is shown in Fig.1 (Khot et al.).

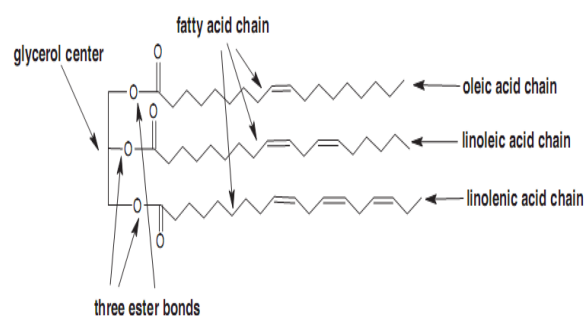


FIG. 1 THE TRIGLYCERIDE CHAIN CONTAINING THREE FATTY ACID BY A GLYCEROL CENTER

TABLE 1 FATTY ACID COMPOSITION OF ZO, PO, SFO AND SO

Fatty Acid	Formula	Structure	[C:DB]*	ZO (%)	PO (%)	SFO (%)	SO (%)
Palmitic	C ₁₆ H ₃₂ O ₂	CH ₃ (CH ₂) ₁₄ COOH	16:0	13.7	39	6	11.0
Stearic	C ₁₈ H ₃₆ O ₂	CH ₃ (CH ₂) ₁₆ COOH	18:0	2.5	2	4	4.0
Oleic	C ₁₈ H ₃₄ O ₂	CH ₃ (CH ₂) ₇ CH=CH(CH ₂) ₇ COOH	18:1	71.1	56	4	23.4
Linoleic	C ₁₈ H ₃₂ O ₂	CH ₃ (CH ₂) ₄ CH=CH-CH ₂ -CH=CH(CH ₂) ₇ COOH	18:2	10	9	47	53.2
Linolenic	C ₁₈ H ₃₀ O ₂	CH ₃ CH ₂ CH=CH-CH ₂ -CH=CH-CH ₂ -CH=CH(CH ₂) ₃ COOH	18:3	0.6	2	1	7.8

* (C, the number of carbon atoms; DB, the number of double bonds)

Triglycerides comprise three fatty acids joined by a glycerol center. Most of the common oil contains fatty acids that vary from 14 to 22 carbons in length, with 1–3 double bonds. The fatty acid distribution of vegetable oils is shown in Table 1 (Güner et al. and Sharma et al.). In addition, there are some oils

containing fatty acids with other types of functionalities (e.g. epoxies, hydroxyls, cyclic groups and furanoid groups) (Gunstone).

It is apparent that on a molecular level, these oils are composed of many different types of triglyceride, with numerous levels of unsaturation. In addition to their application in the food industry, triglyceride oils have been used for the production of coatings (Bussell), inks (Cunningham et al), plasticizers (Hodakowski et al.), lubricants (Salunkhe et al.) and agro-chemicals (Trecker et al and Force et al). In general, drying oils (these can polymerize in air to form a tough elastic film) are the most widely used oils in these industries, although the semi-drying oils (these partially harden when exposed to air) also find use in some applications. The polymers obtained from natural oils are biopolymers in the sense that they are generated from renewable natural sources; and often biodegradable as well as non-toxic. Plant oils containing epoxy groups are important oleochemicals. The major application for these oils is their use as a PVC-plasticizers and stabilisers, because of their ability to catch free HCl and thus slowing degradation. In addition epoxidized vegetable oils (EVO) can be used as reactive diluents for paints and as intermediates for polyurethane-polyol production (Eierdanz).

Recently, bio-based thermosetting polymers from vegetable oils such as epoxidized soybean oil (ESO), epoxidized palm oil (EPO), epoxidized castor oil, epoxidized linseed oil, and epoxidized canola oil have been synthesized in several studies (Park et al and Crivello et al). EVOs possess functional epoxide groups, which can react with suitable curing agents to form an elastomeric network. However, vegetable-oil-based polymeric materials show low mechanical strengths. Several researchers have studied the preparation and mechanical properties of bio-based composite materials derived from soybean oils and glass fibers (Miyagawa et al- Miyagawa et al). Park et al. and Miyagawa and coworkers investigated the thermophysical and mechanical properties of epoxidized-vegetable-oil-modified epoxy materials. Hong and Uyama and coworkers reported the fabrication and characterization of biobased nanocomposites from functionalized vegetable oils and organically modified layered clays (Lu et al. and Hiroshi et al.).

Clay can be chemically modified to make the clay complexes (Polyamide (PA)/clay and, polystyrene (PS)/clay, polymethylmethacrylate (PMMA)/clay,

polypropylene (PP)/clay, and polyurethane (PU)/clay nanocomposites) compatible with organic monomers and polymers (Lu et al. and Hiroshi et al.). Clay, an inexpensive natural mineral that has been used as filler for rubber and plastic for many years, is easy availability, low cost and more importantly environmentally friendly.

The use of many waste products as engineering materials is of major concern to engineers due to their applications for different objectives. For this reason, research on the use of waste products will help to solve many environmental problems, and create new useful findings in the field of engineering. Many researchers have worked to evaluate the waste materials to lower the pollutant effects to the natural environment. The quantity of FA produced from thermal power plants in Turkey is approximately 15 million tons each year, and its percentage utilization is less than 5% (Akkaya). FA, a by-product of coal combustion, is frequently used in concrete production as an inexpensive substitute for Portland cement. Its pozzolanic properties improve the strength of the concrete, and its small particles make the mixture easier to knead (Pei-wei et al.). Indeed, there is an extensive bibliography on the use of FA as a component of concrete (Jiménez et al. and Chindaprasirt et al) and the changes that its addition induces in both mechanical (Topçu et al) and thermal (Demirboğa et al.) terms. Balo and coworkers produced composite materials with different EVO-FA-C and analyzed the physical-mechanical and thermal properties of these materials. When the FA and EVO ratio is increased, low compressive-tensile strength, low thermal conductivity, and high abrasion loss are obtained; while when the C ratio is increased, high compressive-tensile strength, high thermal conductivity, and low abrasion loss are obtained. The minimum thermal conductivity of 0.273 W/mK is observed with the samples containing ESO-FA-C. It is increased with the decrease of ESO and FA. The compressive and tensile strengths are varying from 13.53 to 6.31 MPa and 1.287 to 0.879 MPa, respectively. The minimum thermal conductivity of 0.255 W/mK is observed with the samples containing EPO-FA-C. The compressive and tensile strengths are varying from 4.26 to 1.5 MPa and 0.722 to 0.428 MPa, respectively. The best sample properties with the samples containing EZO-FA-C are determined as follows: thermal conductivity of 0.258 W/mK, compressive strength of 4.37 MPa, tensile strength of 0.731 MPa, abrasion loss of 1.04% and mass of 198.72g. The lowest value of the thermal

conductivity, compressive-tensile strength and mass in produces are obtained for sample produced with 50% EVO/70% FA/30%C. The lowest value of the abrasive loss is determinate for sample produced with 40% EVO/30% FA/70% C. The effect of FA, C, perlite and epoxidized linseed oil on the thermal and mechanical properties of construction materials have been investigated by Balo et. al. The compressive and tensile strengths varied from 10.01 to 1.107 MPa and 8.38 to 1.013 MPa, respectively. The minimum thermal conductivity of 0.313 W/mK observed for the sample made with a 60% FA/30% C/10% P ratio and 50% ELO is processed at 200°C. It is increased with the decrease of ELO and FA. Results indicate an interesting potential for the FA recycling and epoxidized linseed oil renewable to produce useful materials (Balo et al).

In present work, FA, C and four different EVO (ESFO, EPO, EZO and ESO) are used to produce of composite materials. The densities and thermal properties of obtained novel construction materials are investigated.

Experimental

Experimental Scope

Fly ash is one of the most plentiful and versatile of the industrial by-products. About 55 million tons of coal and lignite is combusted in Turkey annually, resulting in more than 15 million tons of fly ash.

In recent years, natural oils have attracted much attention as raw materials for the preparation of resins and polymeric materials, to replace or augment the traditional petro-chemical based polymers and resins. Soybean oil, olive oil, sunflower oil and palm oil are some of the cheapest commercially available vegetable oils.

This study is aimed at assessing the feasibility, in technological terms, of FA disposal and EVO in C bodies used in insulation material making.

Materials and Methods

EVOs (EZO, EPO, ESFO, ESO), FA and C were used as the raw materials to produce the construction material samples. ASTM C618 (Class C), FA, from Kahramanmaraş (Afşin-Elbistan Thermal Power Plant) in Turkey was used in this study. The material has a density of 1.5 g/cm³ and a thermal conductivity coefficient of 0.93 W/mK. EVOs and C (whose density is 2.24 g/cm³ and the thermal conductivity coefficient is 0.511W/mK.) were obtained from Konsan Inc. in Adana and Aslan Corporation in Elazığ in Turkey, respectively. The EVOs are cured with different

anhydrides in the presence of various catalysts such as tertiary amines or imidazoles. The physical and chemical characteristics of the EVOs used in this study are summarized in Table 2. Figure 2 shows the chemical structures of ZO, EZO, PO, EPO, SFO, ESFO, SO and ESO. The chemical compositions for the FA and C are shown in Table 3.

TABLE 2 PHYSICAL AND CHEMICAL CHARACTERISTICS OF EZO, EPO, ESFO AND ESO

PROPERTIES	EPOXIDIZED VEGETABLE OILS			
	EZO	EPO	ESFO	ESO
Appearance at room temperature	Thick to green liquid	Thick to orange liquid	Thick to yellow liquid	Clear to yellow liquid
Brilliance	< (P-CO) : 412	< (P-CO) : 391	< (P-CO) : 385	< (P-CO) : 400
Acid value	(KOH g) : 1.11mg	(KOH g) : 1.14 mg	(KOH g) : max. 1.5 mg	(KOH g) : max. 2 mg
Iodine value	< % 0.83	< % 0.44	< % 1.5 - % 1.7	< max. % 3
Oxirane value	% 4.14	% 3.75	% 4.5 - % 5.2	% 6.4
Thermal conductivity coefficient	0.14 W/mK	0.144 W/mK	0.135 W/mK	0.136 W/mK
Density (25 °C)	0.9 - 0.936 g/cm ³	0.897 - 0.940 g/cm ³	0.925 - 0.979 g/cm ³	0.985 - 0.995 g/cm ³
Saponification number	188 - 196 (KOH g)	173 - 77	163 - 169	183 - 185
Flow point	17°C	4°C	1°C	-1°C
Boiling point	167°C	145°C	138°C	150°C
Ignition point	339°C	304°C	297°C	310°C
Viscosity	276 mPa.s (at 29°C)	239 mPa.s (at 40°)	143 mPa.s (29°C)	325 mPa.s (29°C)
Refractive index (at 29°C)	%1.865	1.398	1.356	1.472
Melting point in water (at 29°C)	< %0.033	< % 0.011	< %0.01	< %0.01
Loss on heating	< % 0.63	< % 0.31	< % 0.46	< % 0.3

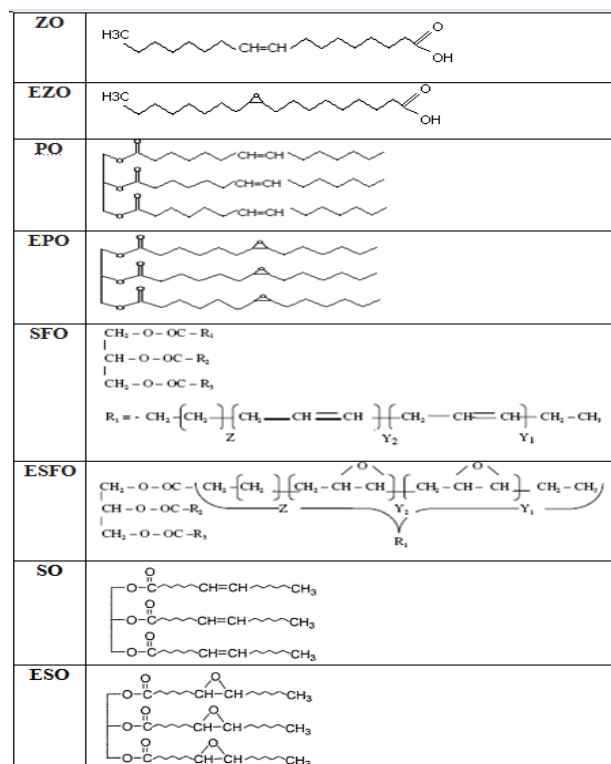


FIG. 2 CHEMICAL STRUCTURES OF EVOs

TABLE 3 RANGE OF CHEMICAL COMPOSITION (WT %) OF FA AND C

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Ignition loss
Fly Ash	21.33	4.025	2.606	36.480	1.032	29.798
Clay	43.645	20.259	12.954	10.150	1.534	9.650

FA and C were used as the main materials to produce the samples. The EVO was used as binder in samples. The standard temperatures and sample compositions were determined from the pretrial. The percentage ratio of the weights of FA and C were 30, 40, 50, 60 and 70. The different compositions of 100 wt% FA-C volume were maintained throughout the series of sample mixes. 100 wt%: compositions of FA and C were prepared using EVO and mixed in predetermined proportions to adjust the appropriate moulding consistency to desired levels. The levels of EVO were selected to give appropriate moulding consistency values ranging from 40 to 50 to sample mixes when treated with a fixed volume of sample. This volume which imparts proper moulding consistency to a sample mix was predetermined from blank trials. The experimental studies were designed to determine the heating conditions most favourable for the EVO/FA/C samples in relation to the properties of the finished products, and to explore the possibilities of reducing the temperatures below those normally used in the brick industry. When process temperature was lower than 160°C, the sample wasn't completely dry. When process temperature was above 200°C, deformation of sample began; and its structure started to crack, at the same time partial fracture in sample happened. Three main groups of samples of EVO, FA and C were produced (160, 180 and 200°C) and specified as 70%C+30%FA, 60%C+40%FA, 50%C+50%FA, 40%C+60%FA and 30%C+70%FA. For each group, separately, EZO-FA-C, EPO-FA-C, ESFO-FA-C and ESO-FA-C mixtures were prepared adding 40%, 45%, and 50% EVO in weight to FA+ C. Hence, 180 different mixes were obtained and cast. The full details and numbers of these samples are given in Table 4. The samples were prepared in laboratory with a small type Lancaster PC-Lab counter-current mixer (size: 16"w. x 30"d. x 40"h) for a total of 5 min. Hand compaction was used. Precautions were taken to ensure homogeneity and full compaction (The full homogeneity mixture was supplied with counter-current mixture. The compaction of the samples was obtained by means of vibration. Test samples of 150mm x 60mm x 20mm were cast using an internal and external vibrator). The samples are casted into 150 x 60 x 20 mm prism steel moulds at normal consistency (Unfired sample shouldn't be ooze from mould.) for tests. After casting, all the test samples were finished with a steel towel. Firstly, the samples are fired at temperature 100°C for 12 h (Predrying was obtained at this temperature) and then fired at temperatures 160, 180 and 200°C for 10 h in electric furnace, respectively. The fortyfive different

results were obtained for the fifteen samples at three different process temperatures (160, 180 and 200°C) from each EVO. The number of total sample was 180. The samples containing EVO, FA and C, after firing are shown in Fig.3.

TABLE 4 THE MIX DESIGN AND NUMBERS FOR SAMPLES.

	EVO								
	160°C			180°C			200°C		
	40%	45%	50%	40%	45%	50%	40%	45%	50%
C 70% FA 30%	1	2	3	4	5	6	7	8	9
C 60% FA 40%	10	11	12	13	14	15	16	17	18
C 50% FA 50%	19	20	21	22	23	24	25	26	27
C 40% FA 60%	28	29	30	31	32	33	34	35	36
C 30% FA 70%	37	38	39	40	41	42	43	44	45



FIG. 3 SAMPLES CONTAINING EVO [EZO (50%), EPO (50%), ESFO (50%), ESO (50%)], FA (50%) AND C (50%), AFTER FIRING

The tests were performed in the Firat University Engineering, Construction Department Laboratories. The density was evaluated for each sample and raw materials using test procedures described in the TS 699 (1987) standard. The results were appraised using equations from TS 699.



FIG. 4 PICTURE OF THE SHOTHERM-QTM TEMPERATURE MEASUREMENT GAUGE

A Shotherm Quick Thermal Conductivity Meter (QTM) based on DIN 51046 Hot Wire Method was used (ASTM C 1113-90). Shotherm-QTM device is the production of Kyoto Electronics Manufacturing, Japan (Fig. 4) with measurement range 0.02–10 W/mK; measurement precision is 5% of reading value per reference plate, and measuring time to be the standard 100–120 s; in which, the hot wire (Cr-Ni) and the thermoelement (Ni Cr-Ni) soldered in the middle, is

placed between the two samples. One of the samples is known thermal conductivity coefficient while the other is the sample to be investigated. Here, the thermal conductivity coefficient is determined by Eq.(1) (Denko et al.):

$$k = K \frac{l^2 \ln(t_2/t_1)}{V_2 - V_1} - H \quad (1)$$

Where K and H are the constants of Shoterm QTM Aparatus and they are taken as 252.10^{-4} and 33.10^{-3} , respectively. Every measurement is repeated three times on three different localities for each sample. The thermal conductivity coefficient (k) is computed by using the average of these nine k values.

This method has wide applications (Willshee et al. and Daire et al) in determining thermal conductivity of refractory materials where, instead of measuring heat flow, the temperature variation with time at certain locations is measured. Being transient in nature, this method takes only a few minutes in contrast to the earlier methods involving steady-state conditions.

Results and Discussions

The results obtained in the tests are shown in Figs. 5–9. They are evaluated and discussed below.

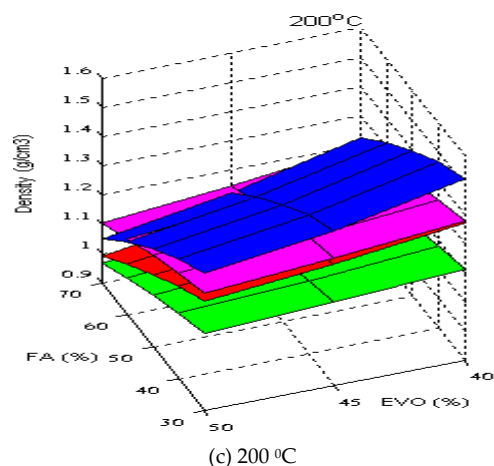
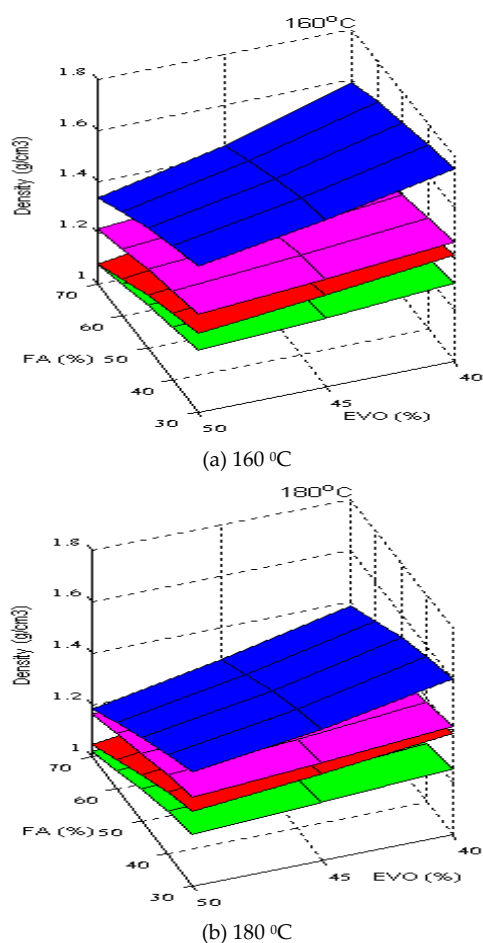


FIG. 5 THE DENSITY, FA AND EVO PER CENT RELATION IN THE SAMPLES

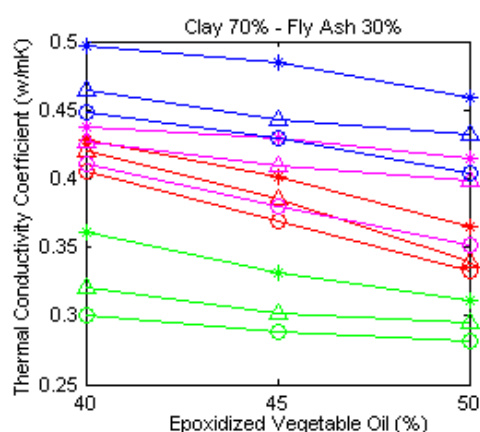
Density

The density is an important parameter for construction material. The low-density products are desirable in terms of transportation, storage and handling. In order to understand the relationships among the sample density, the constituent materials and the firing temperature, we first need to consider the density of the component materials. The densities of ESO (0.985–0.995 g/cm³), EZO (0.9 g/cm³–0.926 g/cm³), EPO (0.897–0.941 g/cm³) and ESFO (0.925 – 0.973 g/cm³) are less than those for either clay (2.24 g/cm³) or FA (1.5g/cm³). It can be certainly seen that density decreases with an increase in EVO content and, because the density of FA is less than that of C, the density decreases with an increase in the FA content. The sample density decreases as the firing temperature increases. This may be due to the loss of water and/or the loss of volatile constituents from the EVO. It is possible that there is a link between sample density and thermal conductivity, especially if that reduction in density is caused by an increase in sample porosity. The density, FA and EVO per cent relation in the samples are shown in Fig. 5. It is observed that densities of the sample are decreased with increasing FA in the mixtures due to the lower density of FA. EVOs are used as binder for sample lowered the densities too. The lowest density, 0.969 g/cm³, is measured for the sample with a 70% FA/30% C ratio and 50% ESFO processed at 200°C. The highest density, 1.754 g/cm³, is obtained for the sample with 30% FA/70% C ratio and 40% ESO treated at 160°C. Thus, the densities varied between 0.969 and 1.754 g/cm³. The density is decreased with the increase in process temperature. The lowest densities for samples with ESFO are 1.078, 1.019 and 0.969 after subjected to 160, 180 and 200°C, respectively. When process temperature is raised from 160 to 200°C, the densities for samples with EZO, EPO, ESFO, ESO are decreased

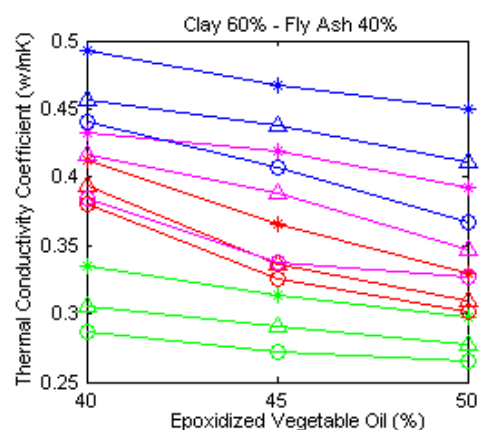
24.69%, 30.18%, 25.91% and 40.07%, respectively.

Thermal Conductivity

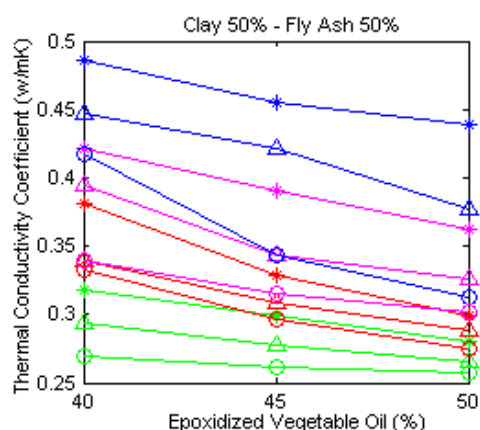
The knowledge of thermal conductivity of construction materials involved in the process of heat transfer is essential in predicting the temperature profile and heat flow through the material. The thermal conductivity of construction material, one of the most commonly used construction materials, is very important. The major factors influencing material's thermal conductivity include chemical composition, pore structure and process temperature.



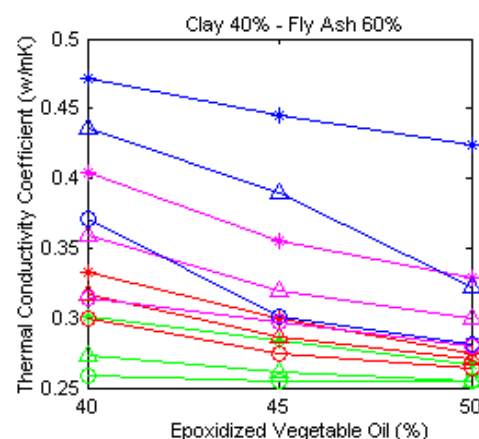
(A) C 70%-FA 30%



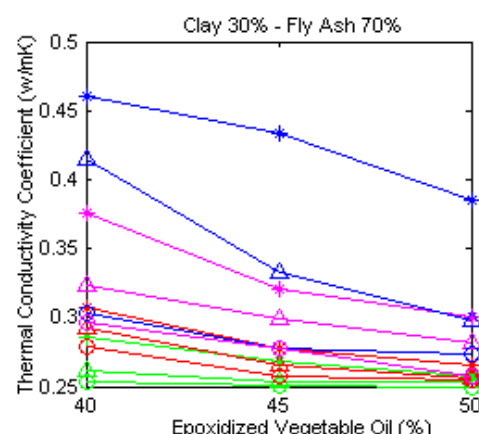
(B) C 60%-FA 40%



(C) C 50%- FA 50%



(D) C 40%-FA 60%



(E) C 30%-FA 70%

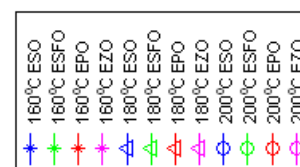


FIG. 6 RELATIONSHIP BETWEEN THERMAL CONDUCTIVITY COEFFICIENT AND EVO PER CENT

In this study, Figs. 6–8 show the effects of EVO (40%, 45% and 50%), FA (30%, 40%, 50%, 60% and 70%) and process temperature (160°C, 180°C and 200°C) on thermal conductivity of the EPO, EZO, ESFO and ESO groups of sample, respectively. The following results have been observed.

The process temperature is an important factor affecting thermal conductivity of end product in the samples. 200°C series has lower thermal conductivity than 160°C series. The thermal conductivity slightly is decreased with increasing temperature as the process temperature gradually is increased from 160 to 200°C, and the decrease has become more pronounced as the temperature is further increased. The decrease in thermal conductivity against sample 45 with ESFO is lower than that of sample 45 with EPO and 3.10% lower than that of sample 45 with EZO and 8.42% lower than that of sample 45 with ESO. The maximum

thermal conductivities of samples with ESO processed at 160, 180 and 200°C are 0.496 (sample code: 1), 0.464 (sample code: 4) and 0.448 (sample code: 7) W/mK, respectively. The highest value of thermal conductivity, 0.496 W/mK, is obtained for the sample with 30% FA/70% C ratio and 40% ESO treated at 160°C. At 180 and 200°C, the thermal conductivity values of the samples with ESO are decreased 6.45-22.59% and 9.67- 29.09%, respectively, compared to those of the samples with ESO processed at 160°C. Sample 1 with ESO processed at 160°C is given the highest thermal conductivity which was 11.96% higher than that of sample 1 with EZO and 13.70% higher than that of sample 1 with EPO and 27.21% higher than that of sample 1 with ESFO. In other words, the maximum reduction in thermal conductivity is obtained at the maximum process temperature (200°C). This is probably related to the increase of porosity due to the high process temperature. There is positive correlation between thermal conductivity coefficient and EVO-FA

The FA ranges from 30% to 70%, while the EVO ranges from 40% to 50%. The samples obtain the lowest thermal conductivity values with FA content of 70%. Increasing the FA ratio is found to impact the thermal conductivity values of samples significantly. Thus, for example, samples code: 37–38–39, 40–41–42 and 43–44–45, the lowest thermal conductivity values are obtained with the highest FA ratio and when the C ratio is low. The maximum thermal conductivity for every group EVO of samples is found for sample 1 (sample code) with FA content of 30%. For 40%, 50%, 60% and 70% FA, the reductions are 5.69-8.54-9.60-11.03%, 6.83-13.96-20.22-26.49%, 9.15-22.77-30.44-32.42% and 9.03-17.16-20.48-23.19%, respectively, compared to the corresponding sample with 30% FA and ESFO, EZO, ESO and 50% EPO processed at 200°C. The thermal conductivity of samples is decreased by 27.21-42.54% with FA content of 70% and EVO content of 40% treated at 160°C. For 30% FA, the increases are 7.25%, 14.15%, 21.05% and 28.27%, respectively, compared to the corresponding sample with 70% FA and ESO, EZO, ESFO and 40%EPO processed at 160°C. The best thermal conductivity values are obtained for samples with ESFO processed at 200°C. The thermal conductivity of these samples is 3.06 -6.25% lower than that of samples with FA content of 30 -70% processed at 180°C and 11.22 -16.89% lower than that of samples with FA content of 30-70% processed at 160°C, respectively, compared to the samples with 30-70% FA at 200°C. This is because the thermal conductivity decreased with increasing FA content. The eduction in

thermal conductivity of sample by means of FA is probably related to the increase of porosity due to the addition of FA in EVO-C, the lower specific gravity of FA, and partly to the amorphous structure of FA, since the thermal conductivity of crystalline silica is about 15 times that of amorphous, it is natural for the samples with amorphous silica to have lower conductivity (Onaran).

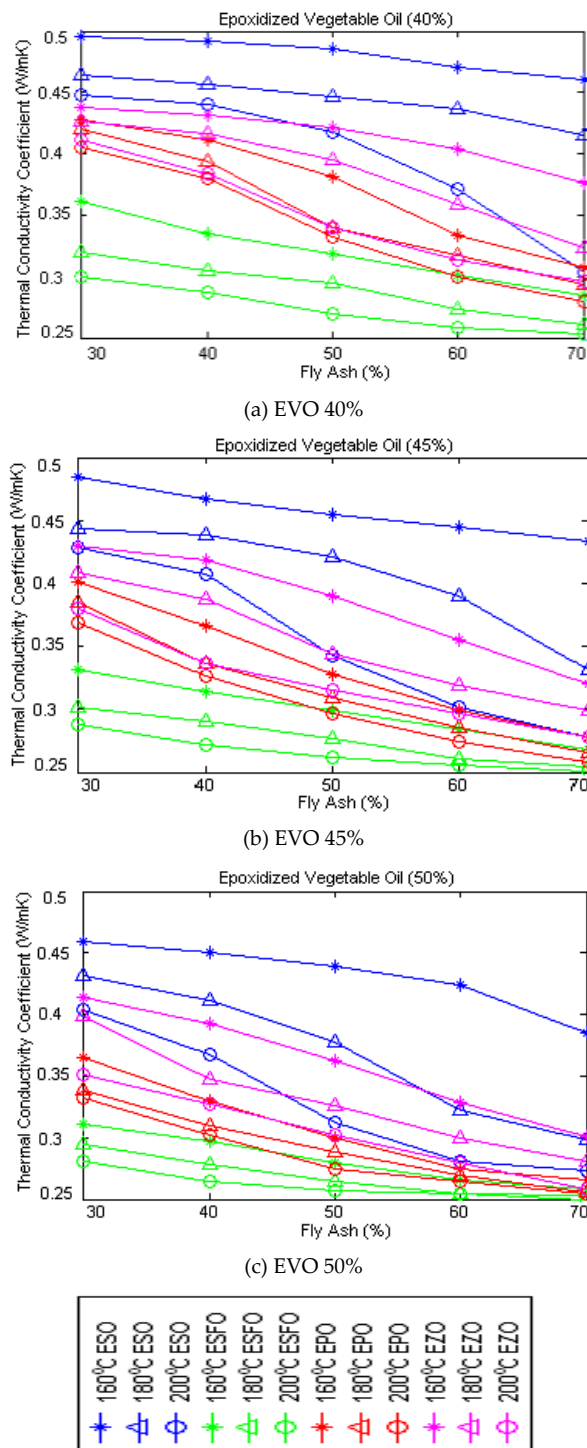


FIG. 7 RELATIONSHIP BETWEEN THERMALCONDUCTIVITY COEFFICIENT AND FA PER CENT

The best thermal conductivity values of all groups are

obtained for the group ESFO, EPO, EZO and ESO, respectively. The reductions in thermal conductivity induced by 30%, 40%, 50%, 60% and 70% FA (70%, 60%, 50%, 40% and 30% C) for group ESFO (50%) are 30.44%, 27.79%, 17.62%, 9.60% and 8.4% compared to the group with 50% ESO treated at 200°C, respectively (Fig.9).

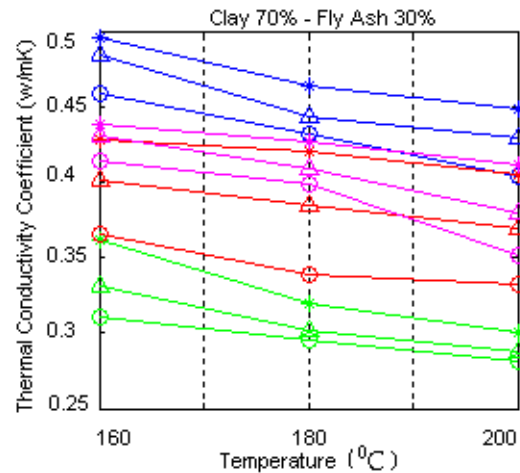
The samples reveal the highest thermal conductivity values with EVO content of 40% for all temperatures. As shown in Fig. 7, the thermal conductivity of samples is decreased by 4.00-0.79% with ESFO content of 45% and 6.30-1.18% with ESFO content of 50% at 200°C. The reductions due to FA ratio for group with 40% ESO treated at 200°C are 9.82%, 16.59%, 25.35%, 24.25% and 9.90% compared to the group with 50% ESO treated at 200°C, respectively (Fig.9). This is because the thermal conductivity decreased with increasing EVO and FA content. The low thermal conductivity of sample by means of FA is probably related to the higher air content, and partly to the amorphous structure of FA, as indicated in Refs. (Onaran and Postacıoğlu). The effect of FA and EVO (ESFO) on group ESFO is greater than that of C for all samples. The thermal conductivity of samples is decreased due to the decreasing of density.

Additionally, Gul et al., Akman and Tasdemir and Blancoetal also reported that the thermal conductivity decreased due to the density decrease of concrete. Lu-shu et al. experimentally formulated a correlation between the density and thermal conductivity, and reported that the thermal conductivity increased with increasing density.

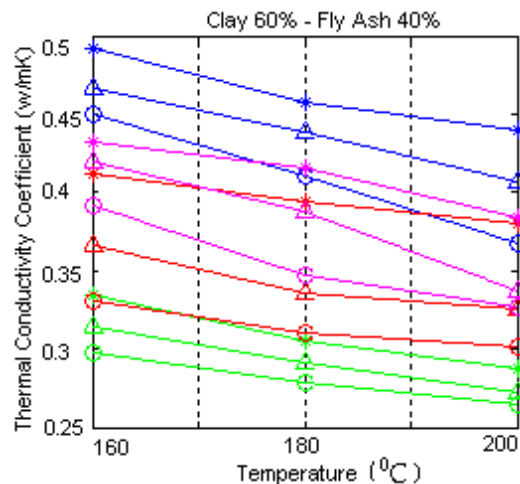
For group EPO, FA and EVO (EPO) treated at 200°C compared to the group EPO at 160 and 180°C reduce the thermal conductivity by 14.59% and 43.37%, respectively. The reductions due to FA (30%, 40%, 50%, 60% and 70%) for group EPO (50%) are 17.82%, 17.71 %, 11.85%, 6.04% and 6.59%, compared to the group with 50% ESO treated at 200°C, respectively (Fig.9). The effect of FA at the 60% and 70% replacements on group EPO is greater than that at the other replacements. Hence, at the 30% replacement of C, both EPO and FA induce approximately equal reduction (Fig. 6-9).

Fig. 8 shows that in group EZO, FA and EVO (EZO) treated at 200°C decrease the thermal conductivity. These reductions compared to the group EZO at 160 and 180°C are 26.49% and 37.22%, respectively. Likewise, the samples reveal the lowest thermal conductivity values with EZO content of 50%. The thermal conductivity of samples are increased about

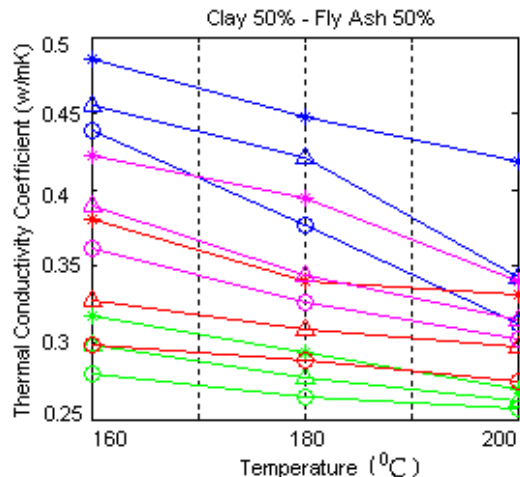
12.83 -14.59% with EZO content of 40% and 7.19-7.63% with EZO content of 45% at 200°C. Thus, it may be concluded that decrease of thermal conductivity coefficient provided by decrease in number of EZO-FA-C grains in unit volume results in more void volume between grains and also increase in number of pores in the EZO-FA-C grains. As expected, thermal conductivity tends to increase when density increases.



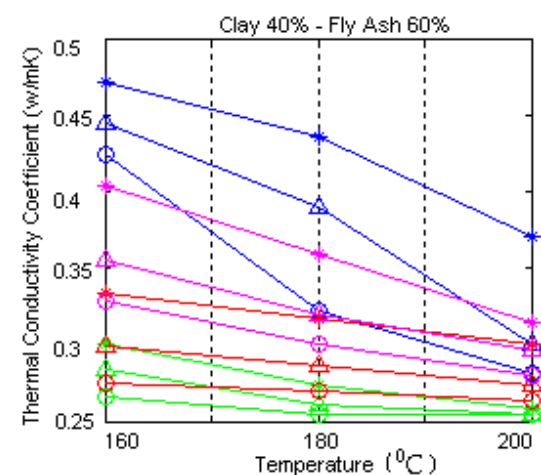
(a) C 70%-FA 30%



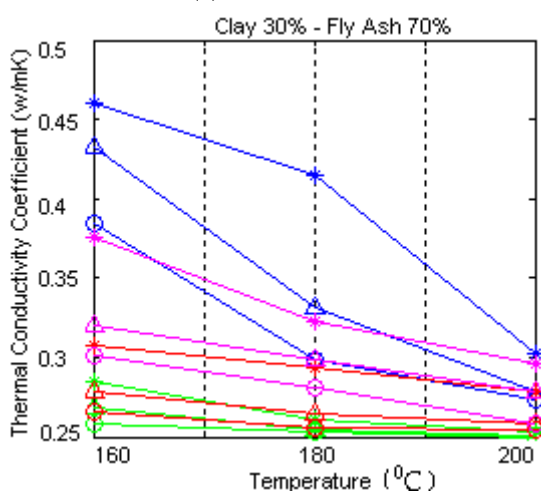
(b) C 60%-FA 40%



(c) C 50%- FA 50%



(d) C 40%-FA 60%



(e) C 30%-FA 70%

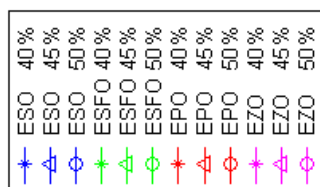
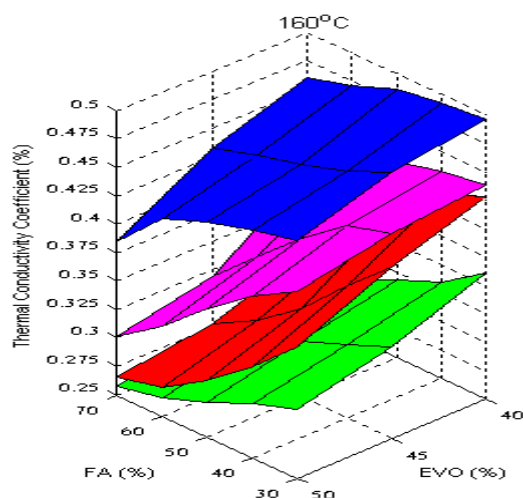
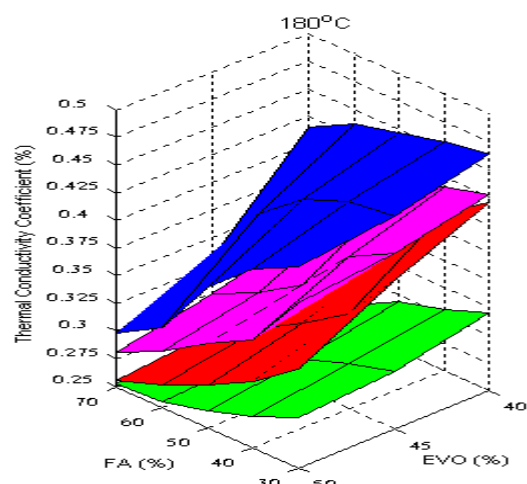


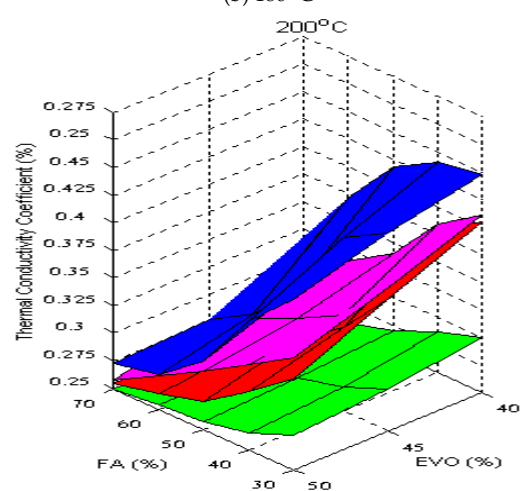
FIG. 8 RELATIONSHIP BETWEEN THERMAL CONDUCTIVITY COEFFICIENT AND PROCESS TEMPERATURE



(a) 160 °C



(b) 180 °C



(c) 200 °C

FIG. 9 RELATIONSHIP BETWEEN THERMAL CONDUCTIVITY COEFFICIENT AND EVO TYPE.

In this study, it is determined that the higher reduction in thermal conductivity in all groups is obtained for the sample with a 70% FA/30% C ratio and 50% EVO processed at 200°C. When the groups are compared with each other, the effects of EVO, FA and process temperature at on group ESFO are greater than those on the other groups. This is due to the fact that the effect of the EVO, FA and process temperature on sample determines the lowest thermal conductivity values for group ESFO. While the effect of the ESFO and FA at 200°C is 16.66%, the effect of the ESFO and FA at 160°C on thermal conductivity is 28.53%. The effect of the FA of 50% ESFO at 200°C on thermal conductivity is 5.69%, 3.01%, 1.16% and 4.00%, respectively.

Thermal conductivities of some types of plaster materials used at present (Blanco et al. and Lu-shu et al) and the most useful of the samples with EVO-FA-C are given at Table 5. It can be seen from this table that the thermal conductivity coefficients of insulation

plasters made by EVO, FA and C are less than most of values stated at T.S.E. standards. The thermal conductivities of samples of groups EZO and ESO are about twice lower than those of the traditional mud bricks, whereas, those of samples of group ESFO and EPO are about three lower than traditional mud bricks (Balo et al).

TABLE 5 THE THERMAL CONDUCTIVITY VALUES MEASURED BY SHOTHERM QTM APPARATUS IN DIFFERENT MATERIALS

Material	Measure Values			Values in Literature		
	Density (g/cm ³)	T _{avr} (°C)	k (W/mK)	Density (g/cm ³)	T _{avr} (°C)	k (W/mK)
Gypsum Block (Perlite)	1.047	40	0.372	0.900	20	0.221
Cement Block (Perlite)	0.427	37.7	0.292	0.1046	20	0.300
Concrete	2.500	27	1.420	2.272	24	1.512
Ceramic	1.077	27.7	0.214	2.00	20	0.988
Strophore	0.016	26.3	0.0308	0.200	20	0.0395
Ytong	0.617	38.7	0.180	0.800	20	0.383
Brick Wall	2.093	45.7	1.148	1.8-2.0	20	0.972
The sample with EZO -FA-C	1.104	31	0.258	-	-	-
The sample with EPO -FA-C	0.99	32	0.255	-	-	-
The sample with ESFO-FA-C	0.969	30	0.25	-	-	-
The sample with ESO -FA-C	1.051	31	0.273	-	-	-

In conclusion, for all groups, the thermal conductivity decreased with increasing EVO-FA content and process temperature. The variation in the reductions may be due to the testing condition and moisture contents. Both EVO (ESFO, EPO, EZO, and ESO) and FA have caused significant reductions in the thermal conductivities. The reduction due to the EVO is greater than that of the FA. The reduction in thermal conductivity is primarily due to the low density of sample with increasing EVO and FA content, and may be partly due to the amorphous silica content of FA. EVO and FA also reduce the thermal conductivity of samples up to 49.59%.

Conclusion

This study explores the possibility of use of FA by-product, natural C and renewable EVO in the sample to produce construction materials. The work presented herein has focused on the thermal conductivity properties of the construction material containing FA, C and EVO. FA (30%, 40%, 50%, 60% and 70%), C (30%, 40%, 50%, 60% and 70%) and EVO (40%, 45% and 50%) are effective for decreasing the thermal conductivity of sample up to 49.59%, which is mainly due to the relatively low conductivity of these admixtures and the consequent low density of the sample. The thermal conductivity and density of sample decreased with increasing FA and EVO content.

Densities decreased from 1.754 to 0.969 g/cm³ with the

increasing FA and EVO content of admixtures. Both EVO (50%) and FA (70%) show the maximum reduction of thermal conductivity with 30% C in all groups, and maximum reduction is observed at group ESO.

EVO is more effective than FA in decreasing the thermal conductivity. The maximum reduction is due to the FA (at 30% by weight of C) and it is 44.95%. The EVO reduces the thermal conductivity, and density of samples. The maximum reduction due to 50% EVO is 40.65%.

The results thus indicate that the samples with EVO-FA-C offer a good alternative for making environmental friendly fired construction material.

Nomenclature

K	Constant of Shoterm QTM Aparatus
H	Constant of Shoterm QTM Aparatus
t ₁	Temperature of startup (K)
t ₂	Temperature of finish (K)
V ₁	The startup voltages of thermoelement (mV)
V ₂	The finish voltages of thermoelement (mV)
k	Thermal conductivity coefficient (W/mK)
T _{avr}	Average temperature (K)
I	Current density in heater wire (A)

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